Chapter 13
Bioreactors

13-1. General

Bioreactor methods, applications, and resulting waste streams are discussed in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

13-2. Technology Description

Bioreactors are contained systems (tanks or ponds) used to degrade contaminants in aqueous solution, utilizing suspended or attached microbial systems. Contaminated soil or sludges may be slurried and then fed into bioreactors for treatment.

a. Suspended Growth Systems.

Suspended growth systems include continuous flow, activated sludge processes, or batch reactors. In these systems, contaminated material is circulated in an aeration basin where microbes aerobically or anaerobically degrade organic matter, and ideally produce CO_2, H_2O, methane, and new cells. The cells form a sludge, which is settled out in a clarifier (Figure 13-1). Sludge is then recycled into the aeration basin to maintain acclimated microorganisms or sent for disposal.

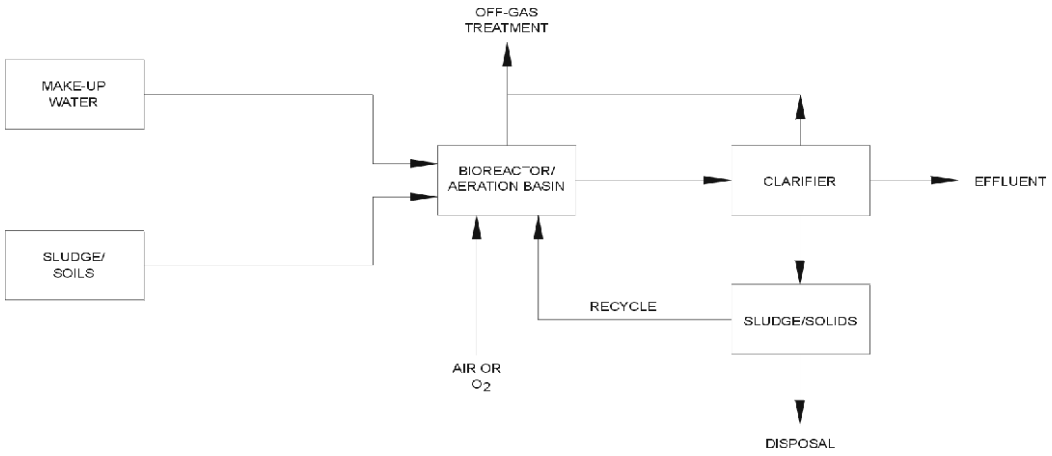

FIGURE 13-1. TYPICAL PROCESS FLOW FOR BIOREACTORS (SUSPENDED GROWTH SYSTEMS)

The levels of contaminants in groundwater usually are not high enough to use suspended growth bioreactors. However, more concentrated waste streams, such as landfill leachate, may be suitable to treatment via suspended growth reactors.

b. Attached Growth Systems.

Attached growth systems (Figure 13-2) include upflow fixed film bioreactors, fluidized bed reactors, rotating biological contactors (RBCs), and trickling filters. In these

systems, microbes grow attached to a support matrix. Liquid waste is circulated through the attached growth system where contaminants are removed and degraded by the microbes. "Clean" water is further processed in a clarifier, where sludge is settled and water that meets effluent criteria is discharged. Attached growth systems include the use of active supports (such as activated carbon) that adsorb the contaminant and slowly release it to the microbial population for degradation. Active supports also include wetland ecosystems and column reactors.

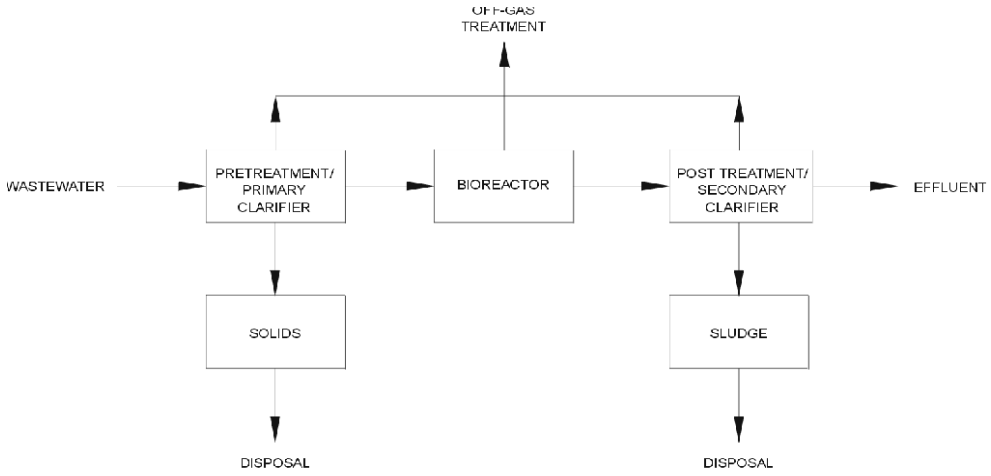

FIGURE 13-2. TYPICAL PROCESS FLOW FOR BIOREACTORS (ATTACHED GROWTH SYSTEMS)

c. Applications.

Bioreactors are used primarily to treat semi-volatile compounds, petroleum hydrocarbons, and halogenated compounds such as chlorobenzene, dichlorobenzene isomers, and some pesticides. Because of the limitations of mixing equipment, the solids content in slurry reactors is usually not more than 20%, by weight.

d. Resulting Waste Streams.

Bioreactors produce four streams that may require additional handling:

- Emissions from equalization tank or other pretreatment operations (may require additional treatment).
- Emissions from bioreactor (may require treatment).
- Effluent water from waste treatment.
- Sludge (may require additional treatment prior to disposal).

13-3. Hazard Analysis

Principal unique hazards associated with bioreactors, methods for control, and control points are described below.

a. Physical Hazards.

(1) *Fire or Explosion Hazards*.
Description. Storage of methanol or other additives or supplements may cause fire or explosion if these materials are spilled and allowed to mingle with incompatible chemicals or are ignited by a source of ignition.

Control. Controls for fire or explosion hazards include:

- Meet mandatory storage requirements of 29 CFR 1910.106, "Flammable and Combustible Liquids."
- Follow appropriate fire and electrical codes.
- Verify that drawings indicate hazardous area classifications, as defined in NFPA 70, Chapter 5, 500.1 through 500.10.
- Use controls, wiring, and equipment near the tanks that conform to the requirements of EM 385-1-1, Section 11, and NFPA 70.
- Use grounded equipment or equipment with ground-fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70.
- Train operators in the chemical hazards associated with storing methanol and other chemical additives used in the process, in the heat of reactions and flammability properties of the chemicals, and in handling and transferring the chemicals.
- Train operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including halting and neutralizing chemical reactions, extracting, decontaminating and stabilizing victims, and in emergency sludge system isolation and shutdown procedures.
- Locate, install, and maintain emergency eyewashes and showers at critical points throughout the system. (See American National Standards Institute ANSI Z358.1 – 1990.)
- Permit only those trained, experienced, and authorized workers to work around the storage areas.
- Direct tank vents to prevent contact with sources of ignition.
- Make fire extinguishers rated for energized electrical systems readily available where electrical equipment is installed and operated.

CONTROL POINT: Design, Construction, Operations, Maintenance

(2) *Confined Spaces*.
Description. Because bioreactors typically generate carbon dioxide gas as a by-product, workers entering tanks or clarifiers may be exposed to confined spaces with oxygen-deficient atmospheres.

Control. Controls for confined-space entry include:

- Train operators and workers in confined space hazards and the unique processes that generate the toxic atmospheric hazards, and on safety procedures to be employed in confined space entry. (See 29 CFR 1910.146.)

- Design the bioreactors to maximize easy operation, physical cleaning, and maintenance to include accessible, adequately sized access doors or entry ports, and to minimize the frequency, duration, and extent of cleaning and maintenance required.
- Develop a pre-entry confined space permit. Implement a confined space entry program to access hazards, including atmospheric testing.
- Provide ventilation of the tank, the vessel interior prior to and during the confined space entry to eliminate oxygen deficient or toxic atmospheres.
- Wear appropriate personal protective equipment (PPE), including respiratory protection including supplied air, as needed.
- Use the Buddy System.

CONTROL POINT: Design, Operations, Maintenance

(3) *Electrocution*.
Description. If permanent and temporary electrical equipment that is not ground-fault protected contacts water or other liquids, an electrocution hazard exists.

Control. Controls for electrocution include:
- Identify on drawings the hazardous area classifications defined in NFPA 70, Chapter 5, sections 500.1 through 500.10.
- Use all controls, wiring, and equipment that meet requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Provide ground fault protection where required by EM 385-1-1, Section 11, or NFPA 70.
- Permit only trained, experienced, and authorized workers in equipment areas.

CONTROL POINT: Design, Construction, Maintenance

(4) *Unguarded Equipment*.
Description. Blowers may be equipped with unguarded pulleys that may cause cuts or entanglement of body parts or loose clothing. Floating aerators may be equipped with unguarded propeller blades.

Control. Controls for unguarded equipment include:
- Use pulleys and other moving or rotating mechanical devices with guards and operate with guarding in place.
- Design and install emergency shut-off systems if there is a threat of workers falling into actively aerated tanks or ponds with bladed aerators.
- Establish lock-out procedures for shutting down aerators prior to operations on a pond or tank water surface.
- Equip tanks with guardrails, grab rails, and ladders as required.
- Prohibit the use of loose clothing around the equipment.

- Train workers in the hazards of working near unguarded machinery and power equipment. Prohibit workers from working in the vicinity of the unguarded hazards. Use the buddy system.

CONTROL POINT: Design, Operations, Maintenance

(5) *Treatment Buildings*.
Description. Permanent or semi-permanent treatment buildings may present life safety hazards, such as inadequate egress, fire suppression systems, or emergency lighting systems, or walkways without fall protection.

Control. Controls for treatment buildings include:

- Meet the following construction requirements for permanent and semi-permanent treatment system buildings: ANSI 58.1, "Minimum Design Loads for Buildings and Other Structures," the "National Fire Code," the "National Standard Plumbing Code," "Life Safety Code" and the "Uniform Building Code."
- Comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations, or local building codes on Superfund, Base Realignment and Closure (BRAC), or Formerly Used Defense Sites (FUDS) project sites.

CONTROL POINT: Design, Operations

(6) *Fire Hazard (Oxygen-Enriched Atmospheres).*
Description. If pure oxygen is used for aeration, workers can be at increased risk of injury from an oxygen-enriched atmosphere that, with an ignition source, can cause fire that can quickly engulf the work area. Usually air, rather than pure oxygen, is used for aeration.

Control. Controls for fire hazards include:

- Design and construct oxygen systems according to NFPA 50, "Bulk Oxygen Systems at Consumer Sites."
- Provide oxygen systems with safety relief devices in accordance with CGA S-1.3, "Safety Relief Devices for Compressed Gas Storage Containers."
- Inspect oxygen delivery systems regularly for leaks.
- Eliminate all sources of ignition during application of oxygen.
- Train workers in the hazards associated with working with pure oxygen.

CONTROL POINT: Operations, Maintenance

(7) *Emergency Wash Equipment*.
Description. Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping and electrical hazards.

CONTROL POINT: Design

(8) *Design Field Activities.*
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from predesign field activities include:
- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Waste Contaminants and Additives.*
Description. Workers may be exposed to waste contaminants by inhalation, ingestion, or absorption. Biological activity of the bioreactors may be enhanced with the addition of nutrients or other chemical agents. These agents may include nutrients, methanol, or other chemicals for pH adjustment (e.g., acids and bases). Workers may be exposed to these chemicals during their application either as a powder or in a liquid state. Overexposure symptoms may include irritation of the eyes, skin, and respiratory tracts.

Control. Controls for waste contaminants and additives include:
- Use personal protective equipment (PPE) during the application process. PPE requirements may include air-purifying respirators with approved filter/cartridges such as N, R or P100, or N, R, or P95 filters for particulates, organic vapor cartridges for vapors, or combination filter/cartridges for dual protection, chemical barrier gloves (e.g., nitrile for some petroleum distillates), splash goggles, and aprons.
- Design mechanical addition systems to minimize exposure.

CONTROL POINT: Design, Operations, Maintenance

(2) *Toxic Intermediate Products.*

Description. Biological degradation of certain organic compounds may produce toxic intermediate products. Degradation of trichloroethylene (TCE) can produce dichloroethylene (DCE) and vinyl chloride (VC). Vinyl chloride exists as a gas and may accumulate to higher levels in collection system boreholes or in the treatment system. Workers may be exposed to intermediate products during operation or maintenance of the system. Anaerobic processes can produce toxic or explosive products, such as methane or hydrogen sulfide, particularly in confined space areas. Workers may also be exposed to VOCs released from aeration tanks.

Control. Controls for toxic intermediate products include:

- Anticipate and understand the generation and management of process products such as carbon dioxide (CO_2), hydrogen sulfide (H_2S), or vinyl chloride (VC) and design for their management.
- Ventilate the affected area.
- Use air-supplied respiratory protection if required (air-purifying respirators are not recommended for vinyl chloride).
- Cover aeration tanks to prevent the release of VOCs into the work environment.
- Monitor the dissolved oxygen and biological oxygen demand (BOD) levels within aerobic bioreactors to determine if aerobic conditions are being maintained.
- Check periodically for the presence of hydrogen sulfide or install automated alarms.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

(1) *Radioactive Materials.*

Description. Radiological materials may have been buried or naturally occurring radioactive material (NORM) may be present in soils, sludge, or groundwater. Some radioactive materials may present an external hazard. All radioactive materials may present an internal exposure hazard through inhalation or ingestion, although this may be a rare hazard.

Control. Controls for radioactive materials include:

- Test the soil, sludge, or groundwater to determine if radioactive materials are present.
- Consult a qualified health physicist to determine the exposure potential and if any necessary engineered controls or PPE are required.

CONTROL POINT: Design, Operations

(2) *Radioactive Devices.*

Description. Fire and smoke detection devices, fluid level devices, and other process monitors and switches may contain radioactive devices potentially exposing workers through lack of identification or mishandling.

Control. Controls for inadvertent handling of exposure to radioactive devices include:

- Workers should be prevented from and warned against tampering with the devices.
- The location of the devices should be recorded so as to safely retrieve and dispose of them in case of a system failure and equipment replacement.

CONTROL POINT: Design, Operations and Maintenance

d. Biological Hazards.

(1) *Opportunistic Insects and Animals*.
Description. For all sites but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect, and arthropod control measures should be considered in any design.

Control. Control of opportunistic insect and animals include:

- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evidence of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.
- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents, and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul cranes and process equipment.

CONTROL POINT: Design, Operations, and Maintenance

(2) *Pathogenic Microbes*.
Description. Bioreactors may expose workers to pathogenic microbes during operation and maintenance. However, exposure to pathogens is usually not a significant concern unless the waste feed contains pathogenic agents. If the bioreactors are equipped with open aerators, microbe-entrained mists may become airborne. Inhalation of pathogenic microbes may cause allergic reactions or illness such as that caused by legionella bacteria. During sludge handling activities, workers' hands may be exposed, resulting in accidental ingestion of pathogenic material.

Control. Controls for pathogenic microbes include:

- Install aerators that minimize generation of mists or install partitions or barriers to contain the mist.

- Test and monitor for suspect microbial pathogens such as legionella when conditions warrant.
- Minimize skin exposure through the use of PPE, such as chemically resistant gloves (e.g., nitrile), splash aprons, face shields, or respirators equipped with N, R or P100 or N, R, or P95 particulate filters approved for protection against microbes.
- Provide adequate hand washing facilities equipped with bactericidal soaps.

CONTROL POINT: Design, Operations, Maintenance

(3) *Sludge Contaminants*.

Description. Biological sludge, after drying, may become airborne and thus be accidentally inhaled or ingested.

Control. Controls for sludge contaminants include:

- Disinfect sludge through pasteurization or long-term storage if necessary. Maintain sludge in a damp condition to minimize free dust; sludge is often dewatered prior to disposal. (Sludge drying beds are the most widely used method of dewatering sludges from municipal wastewater in the United States. Pathogens are usually a greater concern for municipal wastewater applications than for hazardous waste applications.)
- Use appropriate PPE such as an air-purifying respirator with N, R, or P100 or N, R, or P95 particulate filters when handling sludge in dusty conditions.
- Provide access to adequate hand washing facilities equipped with bactericidal soaps.

CONTROL POINT: Operations, Maintenance